Archives of Phytopathology and Plant Protection

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/gapp20

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ARCHIVES OF PHYTOPATHOLOGY AND PLANT PROTECTION
https://doi.org/10.1080/03235408.2021.1938354

Acaricidal and ovicidal properties of *Lippia alba* essential oil and its chemical constituents against red spider mite, *Oligonychus coffeae* Nietner (Acari: Tetranychidae) infesting tea crops

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ABSTRACT

The red spider mite, *Oligonychus coffeae* Nietner (Acari: Tetranychidae), is a prevalent mite pest damages tea crops. The present study evaluated the efficacy of *L. alba* essential oil against *O. coffeae*. GC and GC-MS analysis of *L. alba* essential oil revealed geraniol (52.19%) and neral (34.13%) as major compounds. The *L. alba* essential oil applied at 1500 ppm exhibited 100% mortality of treated mites 48 h after exposure through fumigant toxicity method, while 99% ovicidal activity of essential oil was achieved at 1000 ppm. Similarly, in fumigant bioassay LC_{50} value against *O. coffeae* was 87.75 ppm for geraniol and 103.49 ppm for neral at 72 h after exposure. The findings suggest that *L. alba* essential oil and its major constituents geraniol and neral could be used as eco-friendly acaricide, and can be incorporated as one of the components in IPM after multi-location field trials.

ARTICLE HISTORY
Received 4 February 2021
Revised 7 May 2021
Accepted 27 May 2021

KEYWORDS
Red spider mite; Acaricides; tea plants; *Lippia alba*; GC-MS

Introduction

Tea, *Camellia sinensis* (L.) Kuntze belongs to the family Theaceae, is a perennial crop, attacked by many yield-limiting insect and mite pests that results in significant crop loss (Hazarika et al. 2009; Majumder et al. 2012). In many tea growing countries, red spider mite, *Oligonychus coffeae* Nietner (Tetranychidae: Acarina), a polyphagous acari, has been reported as a major mite pest of tea crop (Muraleedharan 1992).

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Worldwide, *Oligonychus coffeae* is distributed across more than 48 countries in the Neotropical, Palearctic, Afrotropical, Nearctic, Australasian, and Oriental regions (CABI 1963; Bolland et al. 1998). This mite pest infects approximately 133 arable and plantation crops in tropics and subtropics including tea crops (Meyer 2001). The red spider mite, commonly known as tea red spider mite or tea red mite or red coffee mite was first time reported in Sri Lanka on coffee plants (*Coffea arabica* L.) (Nietner 1861), and in Northeast India from the early days of tea cultivation, the red spider mite was known to be a mite pest of tea crops (Peal 1986). *Oligonychus coffeae* caused significant yield loss of harvestable shoots in tea crop amounting to 11 to 55% of total production (Kachhawa and Kumawat 2018). The adults and nymphs of red spider mite lacerate the cell on the upper side of fully matured tea leaves by leaving only the midrib and veins, leading to high defoliation of whole plant (Deka et al. 2017).

Several cultural, mechanical, chemical, and biological methods have been used for management of *O. coffeae* on tea crops (Babu 2010; Mamun et al. 2016). Worldwide, many acaricides, such as Ethion, Fenazaquin, Hexythiazox, Propergite, etc., have been used for the management of *O. coffeae* (Babu 2010; Marcic 2012; Mamun et al. 2016; Deka et al. 2017), but extensive use of such chemicals against this mite pest has led to a number of problems like resistance development, environmental contamination, health hazards, increased cost of applications, etc. (Hazarika et al. 2009). In addition, in tea export there is a need to fulfill with the export requirements on the safe use of pesticides (Babu 2010; Roobakkumar et al. 2010). Therefore, implementing non-chemical strategies for management of mite pest have received attention of tea growers after execution of Plant Protection Code (PPC) by Tea Board of India that specify the choice-based acaricides against mite pests for application in tea crops (Gurusubramanian et al. 2008; Babu 2010). To reduce the uses of acaricides against red spider mite in tea crops, exploring non-chemical control strategies has become essential (Gurusubramanian et al. 2008). Therefore, tea growers are trying to find out some substitutes of synthetic pesticides to protect their crops by pest infestation which are vital for production of tea in a sustainable way.

Application of plant based acaricides such as plant extract and essential oils has become a potential alternative of synthetic acaricides by exhibiting lesser toxicity to the non-target organisms, easily biodegradability, and promising control on insect pests (Mdoe et al. 2014). At present, both extracts and essential oils isolated from higher plants showed potential efficacy against both stored and field insect pests (Bakkali et al. 2008; Park and Tak 2016; Khan et al. 2018; Pandey et al. 2018; Rizvi et al. 2018). Besides, essential oils are less harmful to the predatory mites and other beneficial insects (natural enemies) present in tea ecosystem, and are normally safer to the both environment and human health (Momen et al. 2001; Momen and Amer 2003).

Lippia alba (Mill.) N.E.Br. ex Britton & P.Wilson, belonging to the family Verbenaceae, is a medicinal and aromatic plant, was native to Central and South America, Mexico, and Texas in the United States (Munir 1993). The species is widely distributed in north India and Northeast India (Pandey and Tripathi 2010). The essential oil of *L. alba* has shown efficient bio-efficacy against many pests and pathogens of economically important agricultural crops both under field and in storage conditions (Mesa-Arango et al. 2009; Peixoto et al. 2015; Pandey et al. 2016), however, the efficacy of *L. alba* essential oil has not been evaluated against red spider mite. Therefore, the objective of the present study was to assess the acaricidal activity of the *L. alba* essential oil and it major constituents against red spider mite infesting tea crops.

Materials and methods

Rearing of mite

Different stages of red spider mite were collected from the research plots of Tea Research Association, NBRR& DC, West Bengal (Elevation 214 m, 88° 55′ 0″ E, 26° 54′ 0″ N), India in 2019. The culture of mite was reared and maintained in the laboratory (26 ± 3 °C, 78 ± 4% RH, and 18 L:7D photoperiod) on a inclined tea cultivar, TV1 following the isolated leaf culture method (Helle and Sabelis 1985). From this culture, the matured mites were transferred onto freshly harvested tea leaves (approximately 6 cm^2) positioned on moistened cotton pads (ca. 1.5 cm wide) in a plastic tray (32 × 20 × 6 cm). The shrunken leaves were replaced with fresh ones at an interval of 3 to 4 days. This pure culture (not exposed to any pesticide) was maintained for more than 30 generations (F1 to F30) and mites were used from this culture for different bioassays.

Plant material collection and essential oil extraction

The leaves of *L. alba* were collected from adjoining areas of NBRRDC, West Bengal, India during April to July 2019. For essential oil extraction, 500 g of freshly harvested leaves with distilled water was subjected to hydro-distillation in a Clevenger-type apparatus for 4 h at 100 °C. The oil was extracted over anhydrous sodium sulphate and kept at 4 °C in the dark for further use.

GC and GC-MS analysis of L. alba essential oil

A 0.1 micro liter of *L. alba* essential oil was applied to Gas Chromatography (GC) and Gas Chromatography-Mass Spectroscopy (GC-MS) analysis. The GC was composed of an Agilent Technology 6890 N gas chromatograph data handling system equipped with a split-split-less injector (split ratio 50:1) and fitted with a FID using N_2 as the carrier gas at flow rate 1 mL/min. During the analysis, HP-5 fused silica capillary column (30 m × 0.32 mm, film thickness 0.25 µm) column was used and temperature program was used as follows: Injection: 220 °C, FID: 250 °C, column: 40 °C for 3 minutes and programmed at 5 °C min^{-1} to 220 °C, 5 min at 220 °C, @ 10 °C min^{-1} to 250 °C and 5 min at 250 °C.

The GC-MS analysis of *Lippia* oil was outperformed through Perkin Elmer Clarus 500 GC (Shelton, CT06484, USA) set with a split-split-less injector data handling system with split ratio was 50:1. The Rtx®-5 capillary columns were used with film thickness 0.25 µm, 60 m × 0.32 mm. In GC-MS analysis helium gas was used as carrier at a flow rate of 1.0 ml/min. The gas chromatograph (Perkin Elmer Clarus 500) was interfaced with a mass detector operating in the mode of EI+. The mass spectra were commonly recorded over 40–500 amu that revealed the total ion current (TIC) chromatograms. The temperature program adopted during the analysis was as the same used for GC analysis as described earlier. The temperatures maintained is as followed: Injector: 210 °C, transfer line: 210 °C and ion source 200 °C. The individual compound was identified by comparing its mass spectra recorded during the analysis with the records (NIST/Pfleger/Wiley) provided by the instrument software (Varian Galaxy software), and by matching their calculated retention indices with GC alkanes standard solution (C_8–C_{20}) as well as available literature. The relative area percentages of each chemical component were obtained from GC-FID analysis.

Acaricidal activity of L. alba essential oil

This experiment was conducted following the fumigant toxicity test of Haider et al. (2017). Tea leaf discs were prepared by cutting the matured leaves in 2 cm diameter size and were positioned on moist cotton kept in a Petri plate. The cotton's moisture was maintained throughout the experiments in order to keep the leaf discs from drying. Twenty adults of red spider mite were taken from the stock culture and were released on to each leaf disc. Six different concentrations including 5, 10, 50, 100, 250, 500, 1000, and 1500 ppm of *L. alba* essential oil were prepared in 2 ml of acetone, and using a glass atomizer, the spray fluid was sprayed separately on the surface of leaf disc containing mites. A positive control, where only acetone was sprayed, a negative control, where water and a standard acaricides at the rate of 666.7 ppm (azadirachtin 5% EC @1:1500) was sprayed also kept in parallel for comparison purposes. To ensure the excellent droplets falling on the leaf disc, distance between the leaf disc and the atomizer was set aside constant (1 foot). The experiment was carried out in three replicates and repeated twice. The observations on mite's mortality were recorded after 24, 48 and 72 h of spray and the total numbers of live mites were recorded with a compound microscope (Olympus, Germany) at a specified 10× magnification.

Ovicidal activity of L. alba essential oil

For evaluation the ovicidal activity of *L. alba* essential oil, 20 gravid females of red spider mite were transferred to each leaf of tea (length: 15 cm and width: 6 cm) variety (TV1) for oviposition. The leaves were kept moistened using the water soaked cotton. After laying the eggs, red spider mites were removed from the leaves. The numbers of eggs laid by female mites were counted under a microscope (Olympus, Germany). Thirty eggs per replicate in each leaf were kept to determine the ovicidal activity of *L. alba* essential oil; the remaining eggs from leaf disc were removed by using a needle. Various concentrations *viz.,* 10, 50, 100, 250, 500, and 1000 ppm of *L. alba* oil were prepared in acetone as mentioned earlier and applied on the leaves with the help of sprayer containing the eggs to study the ovicidal activity. Each of the experiment was carried out in three replicates with a positive control (acetone), a negative control (water), and a standard acaricides at the rate of 666.7 ppm (azadirachtin 5%EC @ 1:1500). After each treatment, eggs hatchability per treatment was studied for a period of 12 days and the percent reduction in hatchability was analyzed using the following formula.

$$\text{Egg mortality }(\%) = 100 - \left(\frac{\text{No. non} - \text{hatched eggs}}{\text{Total no. of eggs}}\right) \times 100$$

Eggs did not hatch after 12 days were recorded as non-viable.

Acaricidal and ovicidal activities of major constituents of L. alba essential oil against red spider mite

In the present study, the major chemical constituents of *L. alba* essential oil were geraniol (52.19%) and neral (34.13%), were further evaluated for their acaricidal and ovicidal activities. Both the components were purchased from Sigma-Aldrich having 98–99% purity for the bioassay tests against red spider mite. The acaricidal and ovicidal activity of both these compounds against red spider mite were tested following the methods as described earlier. The most commonly used synthetic commercial acaricide, azadirachtin 5%EC was assayed for comparing their effectiveness with selected compounds following the same procedure.

Data analysis

The data recorded from both acaricidal and ovicidal experiments were transformed to percentages prior to the one way ANOVA analysis. The control mortality of mites was corrected using Abbott (1925) formula. The treatments were compared with control using Tukey's post-hoc Honestly Significant Difference (HSD) test to separate the means at the 5% significance level. The critical difference (CD) was calculated by following the methodology of Snedecor and Cochran (1989). LC_{50} value of *L. alba* essential oil was calculated after the recorded values were pooled for log dose probit analysis through SPSS 17. The LC_{50} results of essential oil and its major constituents are represented as the slope ± Standard Error (SE), LC_{50} (at 95% confidence interval), and chi-square value. All the analyses were done using SPSS 17.

Results

Essential oil composition of L. alba essential oil

The extracted essential oil yielded an average of 0.004% of essential oil on fresh weight basis. The chemical analysis of the oil revealed identification of sixteen compounds, representing 98.9% (area percent) of the total oil composition. The identified compounds with their respective retention index and percentage composition are presented in Table 1. Two monoterpenes including geraniol and neral were the major components of the essential oil comprising 52.19% and 34.13% area percentage, respectively (Table 1). However, α-Copaene, (z)-Isocitral, Cubebol, α-Humulene, and β-Pinene oxide were reported in trace amounts (Table 1).

Acaricidal activity of L. alba essential oil

The acaricidal activity of *L. alba* essential oil reported in the present study is shown in Table 2. The study indicated that the essential oil was effective at a concentration of 1500 ppm, causing 100% mortality of red spider mite within 48 h after spray. While 100 ppm of the essential oil, at the same period after spray, exhibited more than 50% mortality of the treated adult red spider mites (Table 2).

Table 1. Chemical composition of *L. alba* essential oil collected from North Bengal, India.

Name of compound	Retention index	% of composition
Linalool	1045	0.34
β-Pinene oxide	1134	0.21
Neral	1246	34.13
2, 7 octadione-1-butoxy	1278	1.03
Myrcene	1360	0.72
α-Copaene	1371	0.43
β-Elemene	1381	0.33
Geraniol	1398	52.19
(*E*)-Caryophyllene	1417	3.07
α-Humulene	1450	0.21
Aciphyllene	1504	0.53
Cubebol	1513	0.31
(*Z*)-Isocitral	1531	0.12
(*E*)-Nerolidol	1556	1.15
Caryophyllene oxide	1579	1.05
Allo-aromadendrene epoxide	1654	3.11

Table 2. Acaricidal activity of *L. alba* essential oil against red spider mite.

		Mean % mortality[a] of red spider mite ± SE after		
Treatment	Dose	24 h	48 h	72 h
Acetone (positive control)	–	0 ± 0.0 [d]	0 ± 0.0[d]	0 ± 0.0[d]
Water (negative control)	–	0 ± 0.0 [d]	0 ± 0.0 [d]	0 ± 0.0 [d]
azadirachtin 5%EC@1:1500	666.7 ppm	20 ± 1.01[c]	56 ± 2.11 [b]	82 ± 2.12[a]
	5 ppm	7 ± 0.14 [d]	23 ± 0.19 [c]	37 ± 0.74 [c]
	10 ppm	17 ± 1.11[c]	30 ± 1.15 [c]	43 ± 1.54 [c]
	50 ppm	27 ± 1.14[c]	43 ± 2.14 [c]	63 ± 2.12 [b]
L. alba essential oil	100 ppm	37 ± 1.24[c]	51 ± 2.24 [b]	80 ± 3.14 [a]
	250 ppm	63 ± 1.28[b]	83 ± 2.14 [a]	87 ± 2.25 [a]
	500 ppm	77 ± 2.16[a]	87 ± 2.17 [a]	90 ± 3.15 [a]
	1000 ppm	83 ± 3.11 [a]	87 ± 3.25 [a]	93 ± 3.45 [a]
	1500 ppm	97 ± 3.43 [a]	100 ± 3.41[a]	100 ± 3.41 [a]
CD		1.77	2.33	2.89

[a]Values signify mean of twenty replications ± SE. Values in the same column with different superscript are significantly different with each other at $P < 0.05$ by Tukey's post-hoc Honestly Significant Difference (HSD) test.

Ovicidal activity of L. alba essential oil

The ovicidal activity of red spider mite's eggs against different concentrations of *L. alba* essential oil is presented in Table 3. It was observed that, in comparison with both the positive and negative controls, *L. alba* essential oil affected the hatchability of eggs significantly. The maximum egg mortality (92%) was recorded when the eggs were treated with higher concentration (500 ppm) which was statistically similar (99%) to the highest concentration (1000 ppm) of *L. alba* essential oil. The concentrations of 250 and 100 ppm achieved 82% and 69% mortality of eggs, respectively. No significant difference in eggs mortality was recorded at lower concentrations, i.e. 50 ppm and 10 ppm as compared to the untreated control ($F = 6.1$, $df = 8$, $P < 0.05$), whereas azadirachtin exhibited 78% ovicidal activity against eggs of red spider mite (Table 3).

Table 3. Ovicidal activity of *L. alba* essential oil on the red spider mite eggs.

Treatment	Dose	Mean % mortality[a] of red spider mite eggs ± SE (after 12 days)
Acetone (positive control)	–	0.0 [f]
Water (negative control)	–	0.0 [f]
azadirachtin 5%EC@1:1500	666.7 ppm	78.3 ± 2.1[b]
	10 ppm	22.5 ± 1.3 [e]
	50 ppm	44.0 ± 1.3 [d]
	100 ppm	69.8 ± 1.4 [c]
L. alba essential oil	250 ppm	82.1 ± 1.9 [b]
	500 ppm	92.8 ± 2.1[a]
	1000 ppm	99.9 ± 3.1[a]
CD		2.43

[a]Values signify mean of twenty replications ± SE. Values in the same column with different superscript are significantly different with each other at *P < 0.05* by Tukey's post-hoc Honestly Significant Difference (HSD) test.

Acaricidal and ovicidal activity of geraniol and neral

During the evaluation of geraniol and neral, major compounds of *L. alba* essential oil against red spider mite's eggs and adults, a significant difference in mortality of eggs and adults were observed at various concentrations. Azadirachtin showed lower LC_{50} value, i.e. 63.35 ppm at 24 h after exposure, followed by geraniol (142.71 ppm) and neral (180.32 ppm) against adults of red spider mite. The maximum ovicidal activity was recorded for the compound geraniol with LC_{50} value of 72.58 ppm after 12 days followed by neral with LC_{50} value of 165.01 ppm. The standard acaricide azadirachtin 5%EC showed 94.86 ppm median lethal concentration which was less than neral (Table 4).

Discussion

The essential oils have a novel modes of action, less or no toxicity to non-target organisms and less harmful to the environment (Pandey et al.

Table 4. Lethal concentrations (LC50) of *L. alba* essential oil major compounds of against red spider mite.

Name of compound	Bioassay	Time (hour)/day	LC_{50} value (ppm)	Regression equation	95% confidence level		X^2 value
					Lower	Upper	
Geraniol	Adulticidal	24 h	142.71	Y = 0.13 + 2.26x	1.723	2.892	7.429
		48 h	107.53	Y = 0.13 + 2.35x	1.862	2.917	17.557
		72 h	87.75	Y = 0.16 + 2.42x	1.898	3.039	22.582
	Ovicidal	After 12 day	72.58	Y = 0.71 + 2.31x	1.819	2.637	18.856
Neral	Adulticidal	24 h	180.32	Y = 0.12 + 2.18x	2.295	3.001	153.464
		48 h	137.37	Y = 0.10 + 2.24x	2.221	2.986	90.742
		72 h	103.49	Y = 0.39 + 2.24x	2.047	2.775	33.458
	Ovicidal	After 12 day	165.01	Y = 0.38 + 2.01x	1.829	2.835	11.850
Azadirachtin 5%EC	Adulticidal	24 h	63.35	Y = 1.28 + 3.49x	2.705	3.952	19.145
		48 h	49.78	Y = 0.29 + 2.77x	2.121	3.121	21.841
		72 h	45.61	Y = 1.13 + 2.33x	1.915	2.760	26.050
	Ovicidal	After 12 day	94.86	Y = 0.91 + 2.07x	1.644	2.384	135.446

2018), and hence natural compounds obtained from essential oils have been recommended as feasible source of non-conventional treatment for control of insect as well as mite pests (Isman 2006). Essential oils derived from plant materials against pests may be capable, less harmful to the nature and biodegradable (George et al. 2008, 2014). In the present study, essential oil of *L. alba* was tested against adults and eggs of red spider mite infesting tea plants.

The chemical analysis of *L. alba* oil revealed that geraniol and neral were the major compounds present in the *L. alba* oil. Similar results were indicated by Glamočlija et al. (2011) who reported geranial (50.94%) and neral (33.32%) as major components in *L. alba* essential oil in Brazil. However, López et al. (2011) reported carvone (38%), citral (33%), and limonene (33%) as the major compounds in essential oils of different specimens of *L. alba* that was collected from different habitats of Bucaramanga, Colombia. In the same series, Mesa-Arango et al. (2009) reported two chemotypes, citral and carvone, and Tavares et al. (2005) reported three chemotypes, carvonem, citral, and linalool in *L. alba* oils. Recently, Gomes et al. (2019) found seasonal variation in the essential oil of two chemotypes of *L. alba*. The variability in the essential oil composition reported in these studies may be due to influence by the geographical and environmental factors (Santos-Gomes et al. 2005). The variation in composition of *Lippia* essential oils also might be affected by the plant developmental stage and period of leaf collection and types of extraction methods used (Santos-Gomes et al. 2005; Pandey et al. 2016).

In the present study, *L. alba* essential oil showed acaricidal activity by exhibiting significant mortality against adults of treated mites. Results revealed that *L. alba* essential oil exhibited a considerable concentration dependent on acaricidal activity against adults of treated mite. Essential oil of *L. alba* at 500 ppm caused more than 77% mortality of mites, and higher concentration of the same increased higher mortality of mites within 24 h after spray. The findings are analogous to the synthetic acaricides used against red spider mites (Sarmah et al. 2016). In the bioassays, all adults of red spider mites were alive even after 24 h immersed in acetone and all the eggs were hatched when treated with acetone.

A large number of essential oils have been evaluated against mites infesting other crops. For example, *Rosmarinus officinalis* L. essential oil (20 and 40 ml/L) exhibited 100% mortality of adults of *Tetranychus urticae* Koch infesting tomato and bean crops (Miresmailli et al. 2006). de Melo et al. (2019) reported more than 80% mortality of *Tenuipalpus heveae* (Acari: Teuinpalpidae) adults infesting rubber plant after treatment with essential oils of clove, cedar, and neem. In another study, these essential oils caused significant mortality of date palm mite, *Phyllotetranychus aegypticus* Sayed where mean reduction of mite population reported were

43.48 mites reduced after field application of thyme essential oil and 49.96 after clove essential oil application (Allam et al. 2020). More recently, neem oil (6.3 No./leaf, 76.6% reduction), citronella oil (7.3 No./leaf, 72.9% reduction), and citrus peel oil (7.0 No./leaf, 74.0% reduction) have also been reported as effective acaricides against citrus leaf mite, *Panonychus citri* (Chinniah et al. 2020). The leaf essential oil extracted from *Protium bahianum* Dalay displayed efficient lethal activity to *T. urticae* with LC_{50} 3.5 ml/L of air) compared to essential oil extracted from fruit which showed LC_{50} 9.1 ml/l of air) after 24 h exposure (Pontes et al. 2010). The efficacy reported in *P. bahianum* essential oil may be due to presence of α-pinene (34%) in fruit essential oil and aromadendrene (20.3%) in leaf essential oil (Pontes et al. 2010).

In a same series of study, *Majorana hortensis* essential oil displayed 42 to 100% mortality of *T. urticae* adults, *Chamomilla recutita* (30 to 85% mortality) and *Eucalyptus* possessed 17 to 80% mortality *T. urticae* at 0.5 to4% after 24 h exposure (Afify et al. 2012). In addition, *Thuja orientalis* essential oil reported 100 ml/l of air (Mozaffari et al. 2012) and *Eucalyptus* oil reported 19.3 μg/cm3 LC_{50} values against adults of *T. urticae* through fumigant toxicity test (Han et al. 2010). Similar results were reported in present investigation, *L. alba* essential oil reported as effective acaricidal agent against *O. coffeae* with least LC_{50} values. In addition, the oil showed efficient ovicidal activity against eggs of *O. coffeae.* A significant reduction in rate of hatching of eggs by *O. coffeae* was recorded at all concentrations of *L. alba* essential oil. Elhalawany et al. (2019) studied the ovicidal activity of Coriander and Rosemary essential oils against eggs of Citrus Brown Mite, *Eutet ranychus orientalis* and reported that essential oil from Coriander was more effective against treated mites with 4.82% LC_{50} values than the Rosemary essential oil after 7 days of exposure. The oil also possessed potential nymphicidal and adulticidal activity. Likewise, in present study *L. alba* EO also possessed ovicidal and adulticidal activity. Since a few accessible acaricides obtained ovicidal activity against red spider mites, *L. alba* essential oil could be predominantly advantageous in the mitigation of red spider mites as it might decrease the necessitate intended for several treatments to kill newly hatched larvae.

Despite the fact that, acaricidal activity of many essential oils has been well documented, the concerned mechanism and effective compounds of the acaricidal activity are not fully understood because of the complex essential oil composition. The efficacy of *L. alba* and other essential oils observed against mites may be due to presence of terpenoids such as eugenol, geraniol, thymol, terpinene-4-ol, and carvacrol (Perrucci et al. 1995; Pasay et al. 2010). Therefore, in this study, both geraniol and neral were evaluated for their efficacy test against adults and eggs of red spider mite in terms of acaricidal and ovicidal activity. Both compounds showed a dose dependent efficacy against red spider mite, and the LC_{50} values determined for geraniol and neral were more than that of neem based acaricide used in this study. In this regard Badawy et al. (2010) studied the acaricidal activity of monoterpenes against the two spotted spider mite, *T. urticae* and reported that cuminaldehyde and linalool had highest fumigant activity with respective 0.31 and 0.56 LC_{50} values, while through contact toxicity test menthol (LD_{50} 128.53 mg/l), thymol (172.0 mg/l), and geraniol (219.69 mg/l) displayed highest acaricidal activity. Besides, at the 20 ml/l concentration, geraniol also possessed 80% ovicidal activity against eggs of *T.* urticae (Salman and Erbaş 2014).

The study indicated that geraniol at a higher concentration of 1500 ppm exhibited more acaricidal activity against red spider mites. Earlier, *L. alba* essential oil and both geraniol and neral have also shown potential toxicity against stored food mites, *Tyrophagus putrescentiae* (Schrank) (Acari: Acaridae) (Jeon et al. 2009), whitefly (Oliveira et al. 2018), and several other insect pests and plant pathogens (Vishwakarma et al. 2015; Kaur et al. 2019) qualify the broad spectrum virtue of *Lippia* oil.

Conclusion

In conclusion, results of the current study discovered that the *L. alba* oil has promising acaricidal and ovicidal activity concerning the efficacy of *L. alba* oil for the control of red spider mite. Application of *L. alba* essential oil may eventually lead to reduction in use of synthetic acaricides in the tea ecosystem. Future research is required to assess the efficacy of both compounds and essential oil in encapulated form in field which will be an important approach that can be exploited to enhance the stability and potency of these botanical substances in IPM (integrated pest management) program. This study will ensure a pest management approach with low-cost, eco-friendly, and nominal residue issues which may provide as a significant tool for mitigation of red spider mite in tea crops.

Abbreviations

NBRRDC	North Bengal Regional Research and Development Centre
GC	Gas Chromatography
GC-MS	Gas Chromatography-Mass Spectroscopy
TIC	total ion current
HSD	Honestly Significant Difference
CD	critical difference
SE	Standard Error
LC	Lethal Concentration
LD	Lethal Dose

Acknowledgements

The authors are grateful to the Deputy Director (Research) North Bengal Regional R&D Centre, Nagrakata, West Bengal India and the Principal, Darrang College (Gauhati University), Tezpur (Assam), India, for supporting the research laboratory facility.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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